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RESEARCH MEMORANDUM

EXPERIMENTAL AND THEORETICAL STUDIES OF PANEL FLUTTER AT MACH NUMBERS 1.2 TO 3.0

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SUMMARY

Some theoretical and experimental flutter results for simplified panels clamped on front and rear edges are indicated and compared. The results of tests on buckled panels clamped on four edges show that, in general, their flutter characteristics cannot be predicted on the basis of the simplified theoretical or experimental results. An estimated flutter boundary is presented for buckled panels clamped on four edges and having various width-to-length ratios. A pressure differential is found to be effective in suppressing flutter. The results of the experimental tests indicate that panel flutter is probably of concern mainly from a fatigue standpoint.

INTRODUCTION

As more airplanes and missiles are being designed to operate at supersonic speeds, there is a continuing concern that portions of the skin coverings may be subject to flutter. Consequently, some experimental and theoretical studies have been made to evaluate some of the significant variables in the problem. The results of these studies may explain the causes of panel failures on some current high-speed airplanes and may also indicate sources of trouble on future airplane and missile designs.

The main purpose of this paper is to present the results of some recent panel-flutter experiments. In addition, a brief summary of some theoretical work on panel flutter is presented and a comparison is made between some of the theoretical and experimental results. The experiments extend previous work (ref. 1) to include greater ranges of Mach number, pressure differential across the panel, and ratios of panel width to length. Most of the tests were made with buckled rectangular panels clamped on either two or four edges and mounted as a section of the tunnel wall. The buckling forces were induced by thermal stresses or by a combination of thermal stresses and applied edge forces. The dynamic pressure was essentially constant (approximately 6.2 pounds per square inch) for most of the experimental tests.

[redacted]

SYMBOLS

d	maximum depth of buckle with no air flow
E	Young's modulus of elasticity
l	panel length in direction of flow
M	Mach number
q	dynamic pressure
t	panel thickness
V	stream velocity
w	panel width, perpendicular to flow

Subscript:

r	reference experimental conditions

RESULTS AND DISCUSSION

Panels Fastened on Front and Rear Edges

Summary of theory.- A summary of some recent theoretical work on panel flutter is shown in figure 1. Several investigators who have worked on panel flutter are listed, and the particular problems treated are indicated by the check marks. The panel configurations that were studied are the flat panel, the buckled panel, and the infinite flat panel on many supports. All the panels were considered two-dimensional both structurally and aerodynamically, and most of the work applied to supersonic speeds. Isaacs (ref. 2) treated the static stability of a buckled panel and, of course, used steady-state air forces. He advanced as plausible the concept that a buckled panel will flutter if it is not statically stable, and on this basis he obtained a design criterion $\left(\text{essentially } \left(\sqrt{M^2 - 1}\,\frac{E}{q}\right)^{1/3} \frac{t}{l} = 0.545\right)$. Hayes (ref. 3), in addition to considering the static stability, also treated qualitatively the dynamic stability of buckled panels, but used only steady-state air forces. Miles (ref. 4) studied the dynamic stability of both flat and buckled panels and used air forces that included first-order aerodynamic damping.

Shen (ref. 5) extended the work of Miles on flat panels by using exact unsteady air forces. Hedgepeth, Budiansky, and Leonard (ref. 6) analyzed the infinite flat panel on many supports and found that static divergence was of concern at subsonic speeds, and flutter was of concern at supersonic speeds. Fung (ref. 7) investigated the static stability of buckled panels and concluded that the height of the buckle was a significant parameter. Nelson and Cunningham (ref. 8) used exact unsteady air forces in their study of the dynamic stability of flat panels. This analysis appears to be the most general and flexible that is available for the single, flat, two-dimensional panel and included a study of the effect of such factors as Mach number, number of modes in the analysis, structural damping, and tension.

The analytical work has contributed to an understanding of the panel-flutter phenomenon, but further work is needed to extend the theories to more practical panels which are not two-dimensional and which may be either curved or buckled in a complex manner.

Comparison of theory and experiment.- Only Isaacs and Nelson and Cunningham obtained results for clamped-edge panels which correspond to those used in these experimental studies. Some experimental results are compared with these theoretical results in figure 2. This figure shows the thickness-to-length ratio required for flutter-free operation of aluminum panels as a function of Mach number. The data are for panels at an altitude of 25,000 feet since this is approximately the equivalent pressure altitude at which most of the experimental data were obtained. (Where necessary, the experimental data were adjusted to this pressure altitude with the relation $\frac{t}{l} = \left(\frac{t}{l}\right)_r \left(\frac{q}{q_r}\right)^{1/3}$. The subscript r refers to the experimental conditions.) The panels used in the experiments were 11.62 inches long and had a width-to-length ratio of 0.69. The boundary representing Isaacs' static stability or flutter criterion for buckled panels is shown, and the circular symbols are the corresponding experimental points. The boundary obtained from Nelson and Cunningham's two-dimensional flutter theory for flat panels is also indicated and the squares are the associated experimental results. The theoretical curves are shown to increase rather sharply at the lower Mach numbers. For Isaacs' results, the increase is due to the use of steady-state linearized air forces which become infinite at $M = 1$. For the curve of Nelson and Cunningham, the increase is due to a change in flutter mode and decreased aerodynamic damping. This latter curve would have a finite ordinate at $M = 1$. Figure 2 also shows that, in general, buckled panels appear to be more susceptible to flutter than flat panels.

Effect of altitude.- The results in figure 2 are for aluminum panels at an altitude of 25,000 feet. Since both experiment and theory indicate that the effect of decreasing the air density is beneficial, it is of interest to note the effect of altitude on panel flutter. Figure 3 shows the variation of the thickness-to-length ratio with altitude for buckled aluminum panels at Mach numbers of 1.2 and 3.0. The boundaries have been determined by adjusting the experimental results from figure 2 to the appropriate pressure altitude with the relation $\frac{t}{l} = \left(\frac{t}{l}\right)_r \left(\frac{q}{q_r}\right)^{1/3}$, which was indicated previously. Figure 3 shows that the thickness-to-length ratio to prevent flutter is reduced as the altitude is increased. Increasing the Mach number from 1.2 to 3.0 raises the boundary somewhat, indicating a slight adverse Mach number effect.

Effect of a pressure differential.- The results discussed so far have been for panels with zero pressure differential between the two surfaces. It was observed during the panel-flutter tests that a positive or negative pressure differential could be used to advantage in stopping or controlling the flutter. Since airplane and missile panels may be subjected to pressure differentials of various amounts, the effect of a pressure differential is of interest.

The effect of a pressure differential on the flutter of buckled panels clamped at the front and rear edges is indicated in figure 4. These results were obtained experimentally with aluminum-alloy, steel, magnesium, and brass panels having a length of 11.62 inches and a width-to-length ratio of 0.69. The ordinate is the nondimensional grouping of aerodynamic and stiffness parameters which was first suggested by Isaacs and which has been found useful in presenting the results of tests on this panel configuration for the range of Mach number tested ($M = 1.2$ to 3.0). The Mach number factor is based on steady-state linearized air forces and is, therefore, not valid near a Mach number of 1.0. The experimental data points indicate the pressure differential, measured in pounds per square inch, required to stop flutter at Mach numbers of 1.2, 1.3, 1.6, and 3.0. A conservative boundary is faired to contain the data points and represents the division between the flutter and no-flutter regions. Figure 4 shows that a pressure differential of the order of a few tenths of a pound per square inch was effective in eliminating flutter on all panels tested, and that the amount of pressure differential required to suppress flutter decreases as the value of the "flutter parameter" is increased. No flutter was obtained on these panels at a value of this parameter greater than approximately 0.44. Variations in the amount or depth of buckling did not appear to affect the results for the range of this variable studied (values of d/l from 0.003 to 0.009).

Panels Clamped on Four Edges

<u>Comparison of experimental results</u>.- Experimental studies on simplified panels clamped on the front and rear edges are useful in investigating flutter trends and in providing experimental verification of existing theories. However, results of tests on panels clamped on four edges are needed to determine the extent to which the results of studies on simplified panels may be applied to the more practical panel configurations.

The results of tests on two buckled panel configurations clamped on four edges are shown in figure 5, and the results are compared with the flutter boundary (reproduced from fig. 4) for panels of the same length (11.62 inches) clamped on the front and rear edges. The one- and two-half-wave types of buckling were easily obtained on the panels clamped on four edges which had width-to-length ratios of 0.83. The flutter parameter is again plotted against the pressure differential, and the boundary and data points indicate the pressure differential required to stop flutter on the panel configurations identified in figure 5. For instance, flutter was encountered on a given panel at values of the pressure differential less than that indicated by the data point and no flutter occurred for higher values of the pressure differential. Boundaries are not drawn for panels clamped on four edges because of the scatter in the limited data available. The data show, however, that panels with the two-half-wave type of buckling require a greater pressure differential to stop flutter than do panels buckled in one half-wave, and that panels clamped on four edges may be either less or more susceptible to flutter than panels clamped on the front and rear edges. In no case was the pressure differential required to stop flutter greater than approximately 0.87 pound per square inch. Increasing the amount of buckling or destroying the symmetry of the two-half-wave type of buckling appeared to have a stabilizing effect on the stiffer panels clamped on four edges.

The values of pressure differential, referred to in the discussion of figures 4 and 5, represent the approximate difference between the static pressure behind the panel and the effective static pressure acting on the surface exposed to the stream flow. Because of the scatter in the data, the general magnitude of this pressure differential and the trends shown should be emphasized rather than the exact values of the pressure differential.

<u>Effect of panel width-to-length ratio</u>.- Panel width-to-length ratios vary over a wide range, and it appears that the width rather than the length may be of more significance for long narrow panels. This observation is supported by the information in figure 6 which indicates the effect of panel width-to-length ratio and summarizes the present flutter experience on buckled panels clamped on four edges. Most of the data were obtained at a Mach number of 1.3 for panels which had no curvature prior to buckling. However, some data are presented for buckled panels with

a slight initial curvature (radius of curvature approximately equal to 48 inches). The panels with width-to-length ratios of 0.20, 0.50, and 0.83 were 11.62 inches long and those with a width-to-length ratio of 2.0 were 5.81 inches long. The panels were buckled by thermal and applied edge forces, and, in general, the types of buckling modes formed were rather complex and strongly dependent on the panel width-to-length ratio as well as the ratio of applied edge forces in one direction to those in the perpendicular direction. The buckled modes usually consisted of a series of approximate half-waves running in the direction of the longer panel dimension and having a half-wave length roughly equal to the shorter panel dimension.

The ordinate of figure 6 is the previously presented panel-flutter parameter, and the abscissa is identical except that the length has been replaced by the width. The straight lines radiating from the origin are lines of constant width-to-length ratios. Moving away from the origin on these lines represents an increase in the panel thickness (or stiffness) since the dynamic pressure was essentially constant for these tests. The solid symbols represent flutter, the open symbols indicate no flutter, and the short dashes represent an estimated flutter boundary based on the experience with these panel configurations. Although additional data are needed to establish more definitely the flutter boundary, it is apparent that the panel width is significant when the panel width-to-length ratio is reduced sufficiently. For example, for panels with width-to-length ratios greater than approximately 0.8, decreasing the length is effective in eliminating flutter. However, for panels with width-to-length ratios less than approximately 0.5, decreasing the width appears to be a more effective method of reducing the possibility of flutter.

Panel flutter can occur throughout the unstable region as indicated by the data points. However, its occurrence may be of a somewhat statistical nature since such factors as variations in the type and amount of buckling and a small pressure differential may reduce or eliminate the unstable region. For instance, the flutter of relatively stiff panels with $w/l = 0.83$ occurred only when the panels were buckled predominantly in two half-waves. Observations of the flutter tests showed that when flutter does occur it is not necessarily immediately destructive but is probably of concern mainly from a fatigue standpoint. The flutter frequencies were predominantly in the 50 to 200 cps range.

As a matter of interest, some of the apparently more critical panels on the Bell X-1A research airplane would lie near the flutter boundary for flight at low supersonic Mach numbers at an altitude of 40,000 feet. A number of current high-speed airplanes have some panels which would plot well within the unstable region, and a few panel failures which have occurred may have been due to flutter.

CONCLUDING REMARKS

Some theoretical and experimental flutter results for simplified panels clamped on the front and rear edges have been indicated and compared. For these panel configurations, the thickness required for flutter-free operation is increased somewhat as the Mach number is increased from 1.2 to 3.0 (at constant density). Increasing the altitude is beneficial in that the panel thickness to prevent flutter is decreased.

The results of tests on buckled panels clamped on four edges have also been discussed, and it was shown that they may be either less or more susceptible to flutter than similar panels clamped only on the front and rear edges. A flutter boundary has been estimated for buckled panels clamped on four edges and having various width-to-length ratios. This boundary indicates that the panel width is probably of more significance than the length for panel width-to-length ratios less than approximately 0.5.

A pressure differential was found to be effective in eliminating flutter, and for the panels tested did not exceed approximately 0.87 pound per square inch.

It was indicated that panel flutter is probably of concern mainly from a fatigue standpoint.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., April 27, 1955.

REFERENCES

1. Sylvester, Maurice A., and Baker, John E.: Some Experimental Studies of Panel Flutter at Mach Number 1.3. NACA RM L52I16, 1952.

2. Isaacs, R. P.: Transtability Flutter of Supersonic Aircraft Panels. U. S. Air Force Project RAND P-101, The Rand Corp., July 1, 1949.

3. Hayes, W. D.: A Buckled Plate in a Supersonic Stream. Rep. No. AL-1029, North American Aviation, Inc., May 10, 1950.

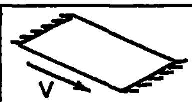
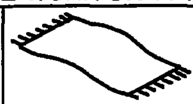
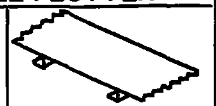
4. Miles, John W.: Dynamic Chordwise Stability at Supersonic Speeds. Rep. No. AL-1140, North American Aviation, Inc., Oct. 18, 1950.

5. Shen, S. F.: Flutter of a Two-Dimensional Simply-Supported Uniform Panel in a Supersonic Stream. Contract No. N5ori-07833, Office of Naval Res., Dept. Aero. Eng., M.I.T., Aug. 6, 1952.

6. Hedgepeth, John M., Budiansky, Bernard, and Leonard, Robert W.: Analysis of Flutter in Compressible Flow of a Panel on Many Supports. Jour. Aero. Sci., vol. 21, no. 7, July 1954, pp. 475-486.

7. Fung, Y. C.: The Static Stability of a Two-Dimensional Curved Panel in a Supersonic Flow, With an Application to Panel Flutter. Jour. Aero. Sci., vol. 21, no. 8, Aug. 1954, pp. 556-565.

8. Nelson, Herbert C., and Cunningham, Herbert J.: Theoretical Investigation of Flutter of Two-Dimensional Flat Panels With One Surface Exposed to Supersonic Potential Flow. NACA TN 3465, 1955.

SUMMARY OF THEORETICAL WORK ON PANEL FLUTTER						
PANEL CONFIGURATION						
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HAYES			✓	✓		
MILES		✓		✓		
SHEN		✓				
HEDGEPETH, BUDIANSKY, AND LEONARD						✓
FUNG			✓			
NELSON AND CUNNINGHAM		✓				

Figure 1

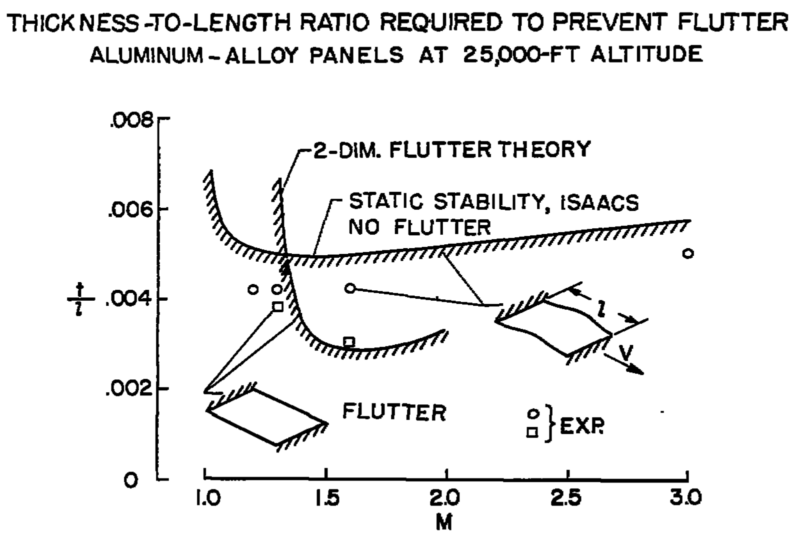

Figure 2

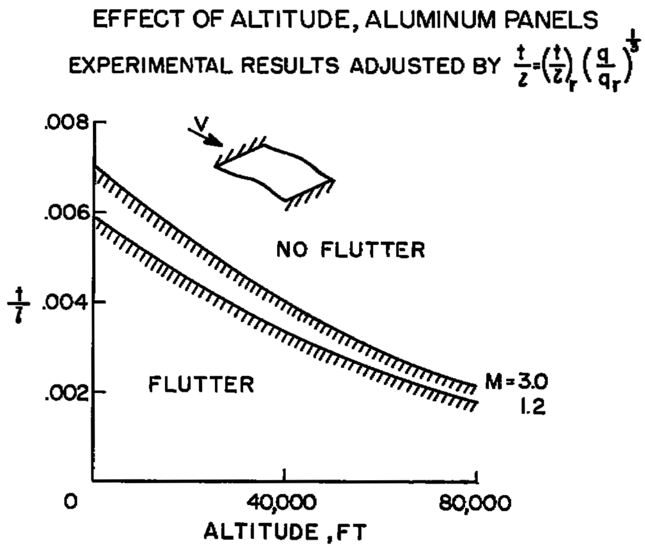

Figure 3

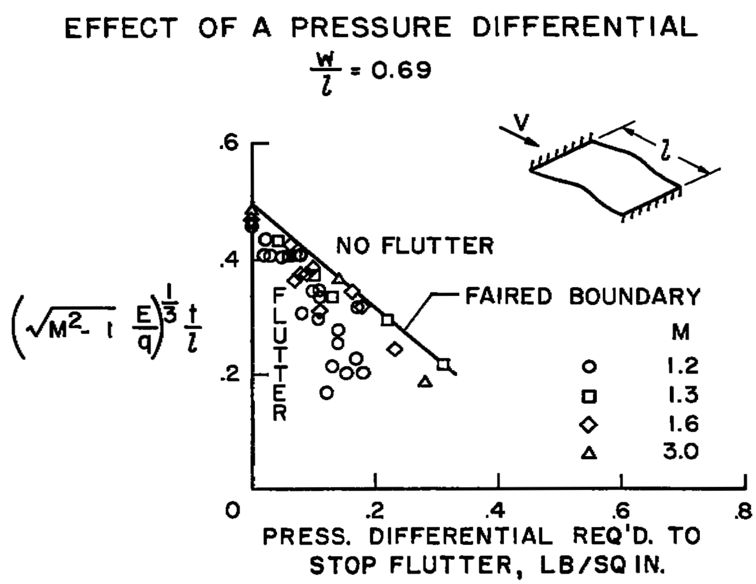

Figure 4

COMPARISON OF EXPERIMENTAL RESULTS
M = 1.3 ; l = 11.62 IN.

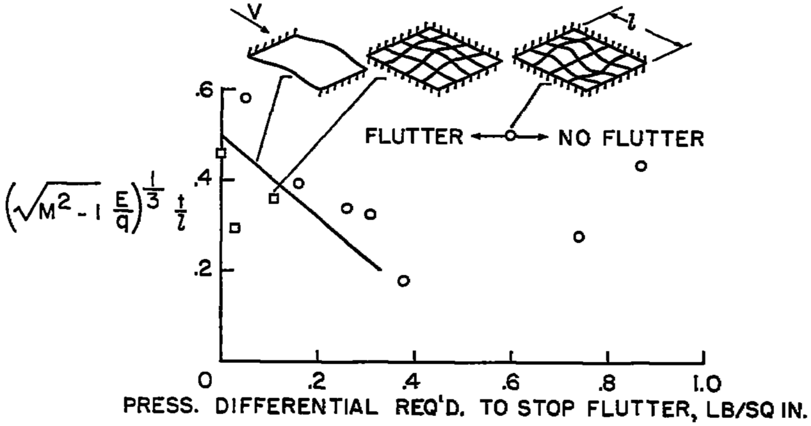

Figure 5

EFFECT OF WIDTH- LENGTH RATIO
BUCKLED PANELS

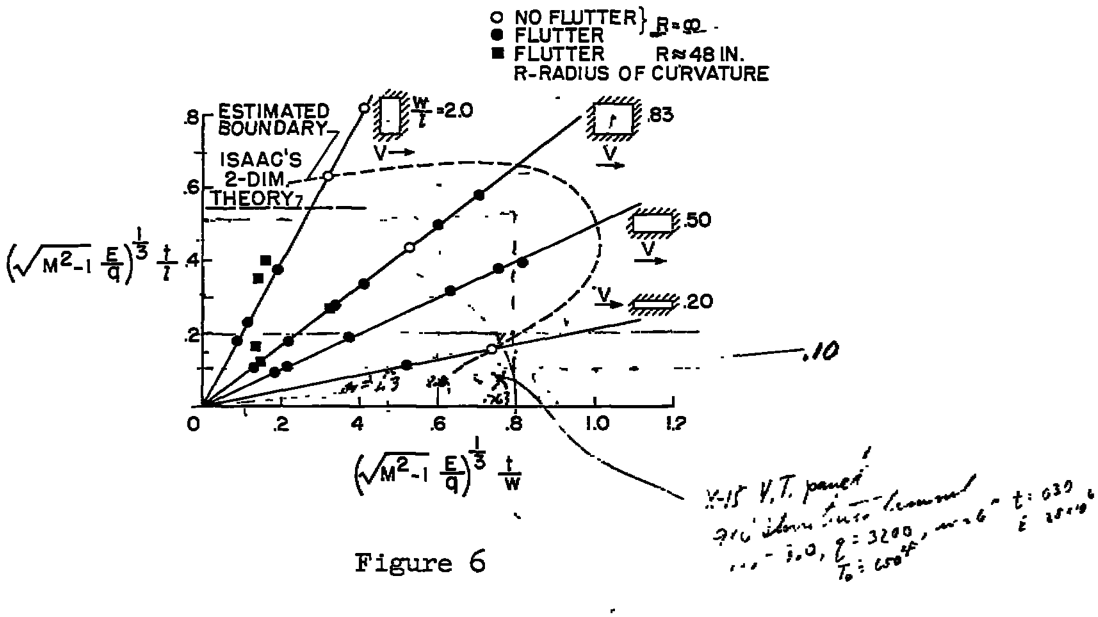

Figure 6

[redacted]